National Park Service Inventory and Monitoring Program

Alpine Monitoring Workshop

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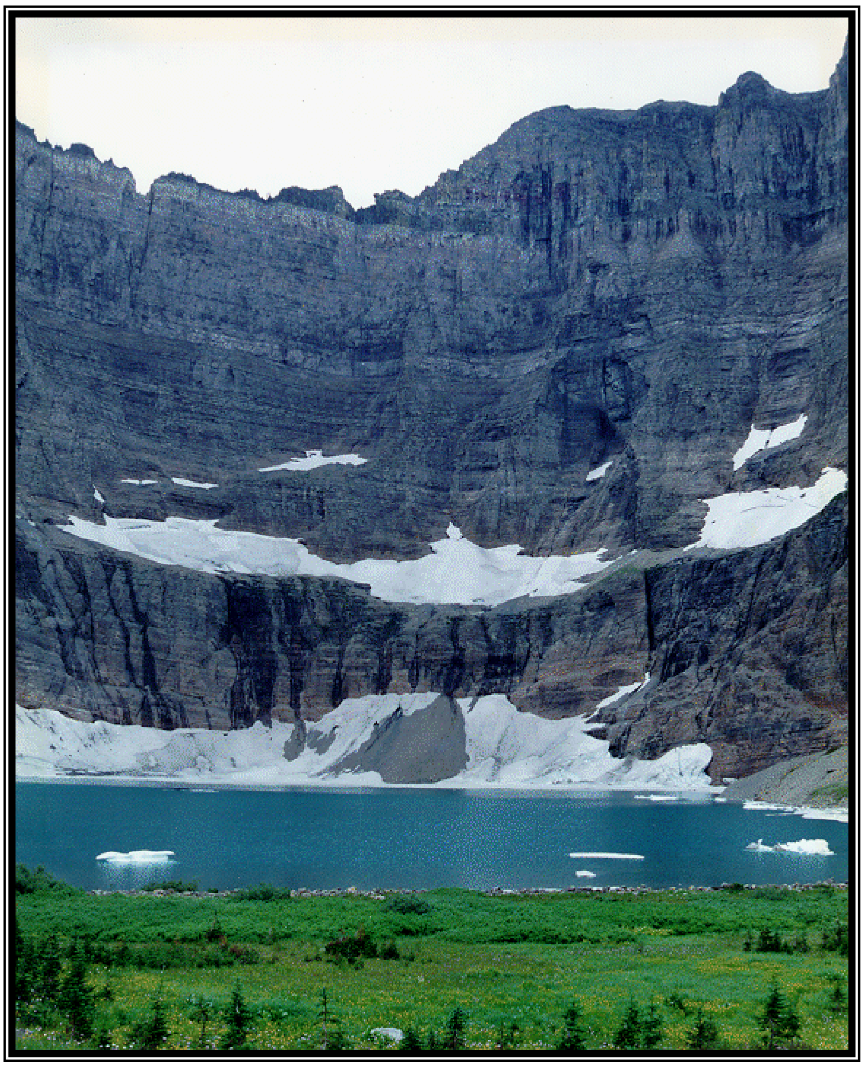

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The awe-inspiring splendor and rugged complexity of high elevation ecosystems have inspired and challenged humans for centuries. Alpine ecosystems[1] have been important throughout history, as physical structures to be revered or conquered, as sites of spiritual inspiration and myth, and recently, as some of the last untamed places on the planet. These communities are also very popular with park visitors. A collection of unique, fragile, sensitive, and beautiful and relatively pristine examples of these rare systems are entrusted to the care of the National Park Service; most of these are the monitoring responsibility of one of a number of western Inventory & Monitoring Networks (i.e. Arctic, Central Alaska, Greater Yellowstone, Klamath, North Coast and Cascades, Rocky Mountain, Sierra Nevada, and Southwest Alaska[2]). Naturally limiting conditions (e.g. short freeze-free/growing season, high radiation, shallow and/or poorly developed soils, physical disturbances from wind, frost and

> *Mountain ecosystems have traditionally been characterized as harsh and variable environments (Billings 1973). Extreme temperatures and large diurnal variation in growing-season temperatures, in conjunction with high levels of ultraviolet radiation, accompany large variations in the amount of precipitation (Bowman 2001, Bowman et al. 2002). The plants and animals that remain above the tree line survive the winter beneath the snow or by keeping living tissues under the soil surface.*
> *Woody vegetation growing at the highest elevations survives by sacrificing windward portions of its structure to protect leeward portions… [, and] most high-elevation species have opted for very conservative growth strategies.*
> *Natural selection has not favored opportunists in this ecosystem.*
>
> \- Seastedt et al. 2004, BioScience 54(2):111-121

[1] We defined “alpine ecosystems” as those biotic communities that exist above timberline; this includes rock, ice, lichen, stunted tree, shrub and herbaceous dominated communities on peaks, ridges, steep slopes, saddles, and cliff bands. The alpine ecosystem extends down through the ecotone with the subalpine forests (including krummholtz), and stopping before the development of closed canopy forest (>80% tree canopy cover). Conversely, when monitoring subalpine, the ecotone (up through the krummholtz) may be included in these sample units also. Further, when the subalpine landscape is characterized by wet or dry meadows, cushion plant communities, avalanche run-out slopes, or otherwise non-forested community determined by past disturbance, wind-scour (or other bio-physical determinant), these high-elevation regions should also be monitored using alpine monitoring methods.

[2] All of these except Artic and Central Alaska were represented at the workshop.

snowpack) mean that slight changes in temperature patterns and nitrogen availability can have significant effects on the composition and function of the system.

High elevation and high latitude communities are expected to be particularly sensitive to climate variation (Spicer and Chapman 1990, Epstein et al. 2004), airborne contaminants (Blais et al. 1998, Williams and Tonnessen 2000, Fenn et al. 2003), exotic pathogens (Campbell and Antos 2000, Fellers et al. 2001) and physical disturbance (Billings 1973). Many complex interactions shape biotic responses: compensatory effects in species populations may stabilize ecosystem-level properties, but a change in abiotic conditions, phenology, or herbivore or pathogen abundance may alter the outcome of species interactions. Where community composition is strongly controlled by physical factors (e.g., hydrology, thermal regime), or where populations occur at the edge of their range, subtle changes in the environment may have significant long-term effects on the larger biotic community. Altitudinal and/or structural shifts in tree line and tree island communities (e.g., Millar et al. 2004), earlier egg laying dates for native birds (e.g., Brown et al. 1999, Inouye et al. 2000) and increased susceptibility of white pine communities (e.g. *Pinus albicaulis*) to an introduced blister rust (e.g., Campbell and Antos 2000) are all potential manifestations of environmental change.

Monitoring the climate, vegetation, and soils across a geographic range of ecologically diverse national parks is a large and complicated task. Therefore, each network is approaching this task somewhat differently based on priority systems, species, stressors, and impending threats. Although none of the NPS I&M networks have selected alpine systems as specific Vital Signs, the alpine ecosystem is an important component of monitoring in western regions (and networks). Because of the unique landscape patterns and highly adapted species and communities coupled with high sensitivity to environmental change, the alpine ecosystems are a preferred class of communities for vital signs monitoring implementation.

Additionally, long-term monitoring of sensitive environments and protected resources deserves special care in design and implementation for minimizing the impacts of the measurement activities on the resource condition and on the monitoring results. Working in alpine environments presents additional challenges and costs related to accessibility and equipment maintenance, so design of our monitoring protocols must address these issues to make the protocols sustainable, affordable, and low-impact.

Workshop Overview and Goals

Monitoring of these important, but isolated and often small areas is a challenge for NPS I&M Networks. Challenges include site accessibility, often hostile weather conditions, relatively poorly understood drivers (e.g., atmospheric chemical deposition and climate change) and response indicators, and potentially complicated interactions between vegetation, fauna, weather, biochemistry and hydrology. This 2.5 day workshop continued the process of discussion and integration of alpine monitoring among NPS I&M networks. These discussions were initiated at the NPS national I&M meetings in Austin (February 2005) and continued informally via email and telephone. This workshop was the product of these initial discussions. Common goals included identification of core commonalities among NPS alpine systems and development specific questions/objectives, a set(s) of recommended measurements and associated analyses. The purpose of this compilation is to inform protocol development and implementation across the region. If multiple networks implement consistent Vital Signs (measures, sample designs, etc.) we all gain analytical and interpretive power, giving our Parks better monitoring results and providing a broad perspective on the health of alpine communities across the west.

Objectives / Guiding Questions

1. What important patterns and processes and community types are common among the networks? (These were identified via electronic communications before the meeting.)
2. Based on the common core patterns and processes, what are the specific monitoring questions and objectives that address these core indicators?
3. Based on the core/common patterns and processes and questions and objectives, what should we measure? And, why is this important to answering the question and/or meeting objectives?
4. Based on the list of pools, populations, and processes we would like to measure, how should we measure these conditions?
   (e.g. what is the sample design (including spatial and temporal components)? what field techniques? what analyses? what level of sensitivity?)

Desired products

1. *List(s) and/or models of common patterns and processes (drivers, stressors, responses);*
   - This product was not formally realized, but this information is contained in the summaries.)
2. *A set of specific monitoring questions and objectives relevant to all (western NPS) alpine systems;*
   - This information is contained in the summaries.
3. *A target set of conditions to measure;*
   a. This information is contained in the summaries.
4. *Draft sampling designs and methods based on numbers 1,2, and 3;*
   - This information is contained in the summaries.
5. *A <u>summary document(s)</u> based on the discussions held in each breakout group in a format similar to a Protocol Development Summary.*
   - These summaries are presented here as a record of the event and the decisions and recommendations made in each group.
6. *A better collective understanding of NPS alpine systems and a basis for future cooperation in design and implementation of alpine monitoring.*

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Terrestrial Communities

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Justification

High elevation and high latitude communities are expected to be sensitive to increased climatic variation (Spicer and Chapman 1990, Epstein et al. 2004), airborne contaminants (Blais et al. 1998, Williams and Tonnessen 2000, Fenn et al. 2003), exotic pathogens (Campbell and Antos 2000, Fellers et al. 2001) and physical disturbance (Billings 1973). Many complex interactions shape vegetation response: compensatory effects in species populations may stabilize ecosystem-level properties, but a change in abiotic conditions, phenology, or herbivore or pathogen abundance may alter the outcome of species interactions. Where community composition is strongly controlled by physical factors (e.g., hydrology, thermal regime), or where populations occur at the edge of their range, subtle changes in the environment may have significant long-term effects on the larger biotic community. Altitudinal and/or structural shifts in tree line and tree island communities (e.g., Millar et al. 2004), earlier egg laying dates for native birds (e.g., Brown et al. 1999, Inouye et al. 2000) and increased susceptibility of whitebark pine (*Pinus albicaulis* Engelm.) communities to an introduced blister rust (e.g., Campbell and Antos 2000) are all potential manifestations of environmental change.

Monitoring Objectives

Vegetation: landscape-level change

- Determine status of, and long-term changes in, the distribution of alpine ecosystems at the landscape scale.
- Determine changes in the structure (density, age/size class distribution) of trees, tree islands, and/or shrubs in the subalpine-alpine ecotones.
- Estimate rates of woody species encroachment into subalpine meadows and/or alpine ecosystems.

Vegetation: ecosystem-level change

- Determine status of, and variability and long-term trends in, species composition in selected alpine ecosystems (e.g., dry meadow, wet meadow, snow bed, fellfield).
- Determine whether species composition (richness, diversity, species' presence/absence) is changing through time.
- Where site access permits frequent revisits, document variability in phenological metrics (e.g., emergence, flowering, fruiting) of selected species.
- Relate variation in species composition, if any, to variation in environmental variables.

Avian communities

- Detect long-term changes in the composition of avian communities in the alpine.
- Determine trends in distribution, relative abundance, and diversity of breeding birds.
- Where site access permits frequent revisits, determine trends in avian annual productivity and survivorship.
- For species of conservation concern, document changes in demographic parameters for selected populations.
- Relate variation in species composition and/or population status to variation in habitat.

Invertebrate communities (SIEN, NCCN)

- Estimate variability and long-term trend in the diversity, distribution and abundance of invertebrates in selected alpine environments.
- Monitor trends in invertebrate species assemblages, secondary productivity and, where site access permits frequent revisits, phenology.

Keystone species[3]

- Estimate variability and long-term trend in the distribution and abundance of keystone and/or indicator species in the alpine.
- For whitebark pine, estimate the current extent of white pine blister rust (*Cronartium ribicola*) infection, the rate of infection, and associated mortality rates. Determine whether rates of infection and mortality in whitebark pine are changing over time.
- For species of conservation concern, document changes in demographic parameters for selected populations.

Abiotic variables

- Estimate variability and trend in air and soil temperatures in selected alpine environments.
- Estimate variability and trend in the timing of maximum and minimum soil temperatures and soil freeze-thaw events.
- Estimate variability and trend in the amount and timing of precipitation (rain, snow), and depth and duration of snowpack, in selected alpine environments collocated with weather stations.

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[3] Keystone species that are relatively well understood and identified as potential subjects for monitoring include whitebark pine, Clark's nutcracker (*Nucifraga columbiana*), and grizzly bear (*Ursus arctos*) in the subalpine. The American pika (*Ochotona princeps*) may be an important indicator of environmental conditions (climate, habitat fragmentation) in the alpine.

- Where applicable, estimate variability and trend in SWE.
- Where applicable, estimate variability and trend in rates of snowmelt.

General Monitoring Approach

We propose a combination of intensively sampled and instrumented 'index' or 'sentinel' sites and less frequently visited, extensive network of sites. Index site locations will be dictated by the availability of weather stations, existing or proposed, for measurement of abiotic variables. Vegetation monitoring plots at index sites should be collocated with weather stations (e.g., $\leq$ 2 km) and/or NADP stations in one or more ecosystems common to the western networks (e.g., dry meadow, wet meadow, fellfield, snow bed, talus, alpine shrub). These physiognomic types are found across a broad geographic area, and targeted sampling should facilitate cross-site comparisons in the future. Inferences regarding long-term trends in species composition at index sites will be spatially constrained, but will be supplemented by less frequent sampling across an extensive network of sites.

Extensive monitoring sites will be selected using a spatially balanced probabilistic sampling framework (e.g., GRTS design), weighted by accessibility and landscape attributes (e.g., elevation, aspect classes). Sites will be visited in the order that they are assigned and sampled if they meet criteria for the target ecosystems. Extensive sites may or may not be instrumented, but at a minimum will include vegetation plots, as described above. The number of sites per park will depend on sample heterogeneity and available funding.

Vegetation:

Plots at all sites (intensive and extensive) may be arrayed within target ecosystems in a spatially balanced, probabilistic design (e.g., systematic sample with simple random start). Vegetation sampling may consist of estimates of cover (e.g., 0.25 m^2) and frequency in nested plots (e.g., 0.25 m^2, 0.5 m^2, 1.0 m^2)

established along transects or grid (e.g., Lesica and Steele 1996, Elzinga et al. 2001). Photographs taken at each set of plots may be used to document cover estimates. Phenological measurements may be made at intensively sampled index sites, or at sites that can be accessed multiple times during the field season. While the group did not agree to adopt the Global Observation Research Initiative in Alpine Environments (GLORIA) protocol for vegetation monitoring, the protocol may contain elements that could be applicable across Networks.

Invertebrates:

Insects are useful as vital signs due to their abundance, importance in ecosystem function (Holloway 1980, Rosenberg et al. 1986), and sensitivity to disturbance. Indicator groups for terrestrial systems may include the Collembola, leafhoppers and chrysomelid beetles, ants, and ground beetles (New 1995). Ants have proven particularly valuable as an indicator group because of their wide distribution and diverse trophic interactions. They are easily sampled and identified, and are responsive to changing environmental conditions (Majer 1983, Erhardt and Thomas 1991). Recent work in subalpine meadows of the Sierra Nevada (Holmquist 2004a, b; Holmquist and Schmidt-Gengenbach 2005a, b) indicates that ant populations, at the generic or perhaps species level, are promising vital signs for monitoring alpine/subalpine meadow health, particularly if combined with monitoring of order-level abundances. Sweep nets, pitfall traps, and vacuum netting methodologies have the most potential as alpine monitoring tools. Sweep net sampling (e.g., 50 sweeps surrounding each vegetation plot) is fast, reproducible, and light and easily transportable in the backcountry, but generally doesn't yield density data. In addition, sweep nets do not sample carabids and ants, which have been shown to be the strongest indicator taxa (Andersen 1990; Andersen and Majer 2004). Pitfall traps (e.g., one trap with 8 cm aperture for every two vegetation plots) do sample carabids and ants well, but are time consuming to place, cause some soil disturbance, and underestimate flying taxa (Holmquist and Schmidt-Gengenbach 2005a).

Vacuums with nets inserted in the intake tube generally offer an improvement in efficiency, especially for ground dwellers (New 1998). This increased efficiency incorporates both abundance and species richness (Buffington and Redak 1998). Vacuums also cause less damage to invertebrates than sweep netting (Callahan et al. 1966) and are particularly efficient at removing fauna in litter and lower vegetation (Stewart and Wright 1995). Vacuum sampling has been found to be most effective when used with some form of enclosure box which is placed prior to suctioning. Holmquist and Schmidt-Gengenbach (2005a) developed a 0.5 m^2 steel quadrat with a conical mesh covering that is thrown toward the target area from a distance and staked down to form a seal with the substrate. The vacuum intake is then inserted through an elasticized mesh aperture for sampling. Multiple passes are made through the vegetation with the vacuum intake over a 2-minute period. The intake is removed, and the vegetation is clipped through the elasticized aperture of the netted quadrat. Following clipping, the intake inserted for an additional two minutes of sampling. The intake is then extracted from the quadrat, the mesh collecting bag is removed from the intake tube, and the fauna and litter are transferred to a bag and placed on ice or, if the work is in a remote location, exposed to ethyl acetate. Sorting is done in the lab. This method has yielded close to 100% recapture of experimentally released crawling and flying fauna (Holmquist and Schmidt-Gengenbach 2005a).

Sampling flooded and dry meadow habitat simultaneously can provide phenological estimates, particularly the timing of emergence. The D-frame hand net is often used for sampling shallow areas and has similar advantages and disadvantages as the sweep net. The most efficient and quantitative device for sampling still, shallow water with emergent vegetation is the throw trap (Kushlan 1981, Holmquist et al., 1989). A throw trap (or drop trap) is a box lacking a solid top or bottom that is cleared of fauna with a net. Throw trapping of well-separated stations is effectively sampling with replacement (Jacobsen & Kushlan

1987), and re-sampling vegetated sites at six month intervals over a period of four years does not cause shifts in measures of vegetation cover or assemblages of mobile fauna (J.G. Holmquist, pers. obs.).

The following protocol is derived from Kushlan (1981) and Holmquist et al. (1989): The trap is a 0.5 m x 0.5 m box without a top or bottom and constructed of sheet aluminum. The clearing device is a 0.5 m-wide framed and handled net (bar seine) with 0.5 mm square mesh. The trap is thrown downwind and then pressed into the sediment. The bar seine is passed repeatedly through the trap for a minimum of ten passes and until three successive passes produce no additional animals. Fauna can be sorted from litter either in the lab or in the field. This method is analogous to the vacuum net, sampling the entire assemblage and yielding density data. However, throw trapping is more time consuming than sampling with the D-frame net, and the latter may be the better choice if funding is extremely limited.

Avian Communities:

Breeding bird surveys and monitoring efforts focused on keystone species may require specific sites and sampling schedules, but when possible opportunistic bird surveys (presence/absence) may be conducted concurrently with vegetation and invertebrate sampling. Bird monitoring in the alpine zone could occur within a larger landscape-level sample design. Siegel et al. (2005) and Siegel and Wilkerson (2005) have used baseline bird inventory data from the North Coast/Cascades Network and the Sierra Nevada Network parks to assess different monitoring approaches and recommend alternatives. One alternative is a landscape-level approach to bird monitoring that employs 5-minute, variable circular plot (VCP) point counts (Reynolds et al. 1980; Fancy 1997; Nelson and Fancy 1999; Buckland et al. 2001). VCP point counts rely upon distance sampling (Buckland et al. 2001), which facilitates the estimation of detection probability—a parameter that may vary greatly by species, habitat, observer, or other factors.

Estimates of detection probability permit the estimation of absolute density of birds across the landscape, a much more meaningful metric than the relative abundance indices that can be produced from point counts that do not incorporate distance sampling.

The landscape-level protocol recommended by Siegel et al. (2005) and Siegel and Wilkerson (2005) also addresses some of the challenges inherent in doing monitoring in vast, rugged parks with large roadless areas; i.e., safety concerns, high travel costs and diverse habitats. To address the first two concerns, the sampling frame would be limited to accessible areas of the parks within 1.625 km of a road or trail. Transects would 'start' from points on trails, and run perpendicularly away from the trails for up to 1.625 km in both directions. More remote portions of the parks would be defined as a separate stratum that may not be sampled at all under likely staffing and funding constraints. This approach would be feasible for parks with good road or trail access to various elevation zones, but the alpine would most likely be less sampled than other zones using a trail-based approach. To address the issue of diverse habitats, an 'augmented, serially alternating' panel design (Urquhart et al. 1998; Siegel et al. 2005, Siegel and Wilkerson 2005) is recommended, wherein approximately half of the annual survey effort would be devoted to surveying transects that are visited annually, while the remaining survey effort would be devoted to one of four panels of additional transects that would be sampled every four years.

An alternative to landscape-level monitoring of birds is to select habitats known to be critical to avifauna, and target those for long-term monitoring. An example of such a habitat for the Sierra Nevada is montane meadows. A long, taxonomically diverse list of bird species depends on meadows for nesting and/or post-breeding habitat, and many of these meadow-breeding species appear to be declining across the Sierra (Siegel and DeSante 1999). It may be desirable to identify areas of the alpine and subalpine that provides critical habitats for breeding birds, including riparian areas, lakeshores, meadows and wetlands. The feasibility of collocating bird monitoring with the index sites and extensive monitoring sites described for vegetation and invertebrates should be evaluated. While collocation is desirable for analysis of relationships among different components of the alpine system, it is possible that objectives for vegetation and bird monitoring may not be met using the same sample sites.

Keystone species:

Sampling designs for individual keystone species (e.g., grizzly bear) will need to be developed by resource specialists, as this expertise was not represented at the September 2005 Workshop. A protocol development summary has been developed for whitebark pine by the Greater Yellowstone Network.

Research, Development and Inventory Needs

Research and development needs for terrestrial monitoring include the development of models for the detection of fine-scale change on the landscape (e.g., detection of diffuse boundaries and separation of spectrally-similar cover types) and delineation of alpine environments on the landscape; methods for detecting change that are platform-independent; and access to new sources of imagery, software, and training that are not cost-prohibitive. Studies of the phylogeography of alpine species may identify relict populations and/or variation in genetic structure that are of relevance to population- and community-scale monitoring, and that can be tied to landscape-scale studies. Inventories that document species composition across a range of alpine environments, and studies linking community composition to environmental gradients, are likewise needed.

While data from index sites may point to relationships between abiotic and biotic variables, experimental work is needed to identify drivers of change. Experiments designed to test the effects of environmental variables (e.g., variation in snow depth and duration, soil temperature, soil moisture, and atmospheric loading) and/or biotic interactions (e.g., herbivory, biological invasions) on community and ecosystem-scale processes are needed in a range of alpine environments. Community and ecosystem-scale responses to N and P enrichment (e.g., Bowman et al. 2006), snow depth (e.g., Galen and Stanton 1999; Chimner and Welker 2005) and soil warming manipulations (e.g., Harte and Shaw 1995; Walker et al. 1999; Wahren et al. 2005) may enable us to make predictions about long-term trends and threshold responses of alpine systems, although the existing studies have been limited to only a few sites. Work focused on herbivory and/or exotic species has occurred primarily in montane and low-elevation systems. Studies of interannual variation in community- (e.g., Walker et al. 1994) or population-level parameters (e.g., Lesica and McCune 2004), may highlight indicator species particularly sensitive to environmental variation and/or suggest whether species establishment is limited by dispersal or other factors. Such analyses may be particularly relevant to issues of invasibility, though are likewise site-specific.

Climate-induced changes in flowering phenology may cascade into insect assemblages and ultimately into bird populations (Smith 1982). Basic research on the biology of species that nest and breed in the alpine (e.g., habitat, diet requirements, distribution, migratory patterns, variation in clutch size, laying dates) will likely be necessary to interpret results of monitoring. Existing information about birds in the Sierra Nevada alpine and subalpine is derived primarily from baseline inventory data (Siegel and DeSante 2002, Siegel and Wilkerson 2004, 2005). Small-scale monitoring of birds at alpine lakes where removal of non-native trout has occurred suggests that increases in abundance of invertebrates and amphibian tadpoles that follow fish removal are also beneficial to birds that rely on these animals for food sources (D. Boiano, Sequoia-Kings Canyon NP, *personal communication*). Monitoring of avian productivity and survivorship in Sierra Nevada montane meadows has demonstrated that capture rates of adults and young, as well as productivity indices have been substantially higher at Yosemite than at Sequoia and Kings Canyon. The reasons for the differences are unknown, but research on effects of air pollution and airborne contaminants, land uses and management practices bordering monitoring sites, and climatic conditions on breeding populations of birds is needed to better understand trends in breeding bird population indices and differences observed between southern and central Sierra Nevada monitoring sites (DeSante et al. 2005).

The distribution of invertebrate populations is likewise poorly studied in alpine ecosystems. Shapiro (1973) describes significant altitudinal migrations for Sierra butterflies. Because of their generally limited dispersal capabilities and/or behavior, even comparatively mobile fauna may be influenced by increasing climatic variation. Species with narrow temperature tolerances, such as alpine meadow grasshoppers (Coxwell and Bock 1995), are likely to be affected strongly by climate. Most studies focused on community-level responses to environmental drivers do not include invertebrates as response variables, and invertebrates do not necessarily respond in the same manner as plants to environmental change. Additional research needs related to invertebrate assemblages include the following: the effects of differing meadow size on assemblage structure; the degree of interchange between meadow assemblages and neighboring habitats (streams, forest); assemblage response to changes in soil moisture and to environmental conditions along topographic gradients; and determination of inputs of windborne fauna (e.g., aerial plankton).

Far-source influences on migratory and resident keystone species (e.g., pesticide effects on miller moths (*Euxoa* spp.), and the effects of environmental change on obligate alpine species (e.g., American pika) will likely have associated impacts on alpine trophic interactions. A resurvey of the historic UC Berkeley Grinnell transects in Yosemite has indicated no populations of alpine chipmunks (*Tamias alpinus*) or pika (*Ochotona princes*) at elevations below 9500 ft. (Patton and

Moritz, *in progress*), consistent with reported extirpation of pika populations in the Great Basin (Beever et al. 2003). The effects of species loss on larger community- and ecosystem-scale processes is largely unknown and likely depends not only on the species lost, but also on the composition of the community that remains (e.g., Larsen et al. 2005).

The effects of biotic and abiotic factors on soil processes (net and gross N mineralization, immobilization, C sequestration, and respiration), decomposition, belowground production, nutrient export/leaching/gaseous losses are well-studied in some systems, but poorly understood in others. Experimental work may identify threshold conditions for key processes across a range of environments. Such research can inform mass balance studies and support modeling efforts aimed at predicting ecosystem response. Measures of seasonally-integrated NDVI and ecosystem-scale C and N flux, and studies of long-term variation in the timing of seasonal transitions (e.g., from frozen-unfrozen conditions, measured with radar remote sensing) may likewise support predictions of broad-scale responses to environmental drivers.

Potential Collaborators

Potential collaborators include USGS-BRD, USGS-EROS, USFWS, USFS-FIA, USFS Research Stations, NASA, NOAA, TNC/Heritage Program, NSF-LTER Network, ITEX Network, non-profit foundations and/or societies (e.g., Whitebark Pine Ecosystem Foundation, Audubon Society, Xerces Society), and University-affiliated institutes and faculty.

Development Schedule, Budget and Interim Products

Estimated costs associated with vegetation monitoring in parks range from $36,000-$70,000 per project for remote sensing-based work, and from $18,000-$60,000 for plot-based work. Estimated costs associated with invertebrate monitoring, concurrent with vegetation monitoring, should fall within the range of vegetation sampling, but rudimentary sampling may be completed for as little as $2000-$5000. Breeding bird surveys and monitoring of keystone species are estimated to range from $25,000-$60,000 per year, depending upon site access and staffing (internal vs. contract). A landscape-level or more intensive, targeted-habitat bird monitoring program is estimated to cost approximately $65,000-$70,000. Costs associated with weather station deployment and maintenance are addressed elsewhere. Protocol development schedules will vary by network, but it is anticipated that draft protocols may be ready as early as FY 2007.

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High Elevation Weather and Climate

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Justification

Weather and Climate are key drivers of ecosystem, community and population functions, making it an important system driver for most other Vital Signs. A key conclusion of this workgroup is that current weather and climate monitoring data from high elevations (not just alpine environments) in western "mountain parks" is insufficient for Vital Signs monitoring. The following *recommendations* represent a first step towards development of an integrated (among NPS networks and with other Vital Signs monitoring within networks) set of high elevation weather and climate monitoring protocols. The monitoring should contribute to understanding whether and how climate is changing and how it is affecting other vital signs and park resources in general.

We identified weather, snow, and glaciers as three largely distinct (in terms of methods) and most important high elevation monitoring needs. An important component of protocol development should be to identify existing monitoring data and programs, determine if they meet NPS monitoring needs (in terms of temporal and spatial resolution), seek to fill in gaps in existing monitoring efforts, and adopt methods that will be both locally and universally applicable.

Weather and Climate monitoring should be a network-based cooperative program. Since there are many common issues and drivers in high elevation parks across the west and in Alaska, high elevation weather and climate monitoring should be integrated through use of common protocols and methods among the networks as much as possible. For common monitoring elements, networks should work together (by developing detailed protocols including SOPs for analysis and reporting) to maximize the value of the work across all involved networks.

Weather and climate

Climate controls ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes underlying the distribution and structure these ecosystems (Schlesinger, 1997; Bonan et al., 2003). The effects of climate are especially visible in the strong zonation and steep elevational gradients displayed by vegetation types in western mountain parks. Plants and animals in alpine environments must deal with short growing seasons with extreme and rapid weather shifts. Temperature is critical; for example, it regulates the "spring pulse," when the snowpack begins melting each spring and quickly releases a large spike of chemicals and nutrients. Atmospheric deposition is a related, important issue in many mountain areas and is fundamentally linked to weather and climate through regional circulation patterns. High-elevation regions are good for connecting these regional and global scale drivers with local effects because of the sensitivity of the organisms and communities.

Snow

A predominate feature of climate at high elevations in the western U.S. is the presence of a seasonal snowpack, a major influence on hydrology, vegetation, and faunal communities (*Jones et al.,* 2001). In the western United States, over half of the water supply comes from the mountain snowpack, and over the past 50 years, warmer winters and springs have led to earlier snowmelt. The fraction of annual streamflow that runs off during late spring and summer has declined by 10 to 25% (Roos 1991; Wahl 1992; Dettinger and Cayan 1995). Snowmelt runoff timing has advanced by approximately one to three weeks in the large majority of mountainous catchments across western North America (Stewart et al. 2005; Regonda et al. 2005). Predictions for the future suggest that these trends are likely to continue. Numerous studies suggest that the timing of snow-fed runoff could shift 30 to 40 days earlier by the end of the 21st century (Stewart et al. 2004; Wood et al. 2004; Dettinger et al. 2004; Jeton et al. 1996). These changes affect ecosystems, economy and agriculture across the region by releasing more water in winter and retaining less water for the summer, when it is needed most.

Glaciers

Glaciers are integral components of mountain ecosystems in the western U.S., and they are retreating rapidly. They affect the distribution of aquatic and terrestrial habitat through their advance and retreat. Glaciers directly influence aquatic habitat by the amount of cold, turbid melt water and fine-grained sediment they release. Glaciers influence park and regional hydrology (quantity and timing) through discharge of glacial melt water with direct effects upon aquatic ecosystems. The sensitive and dynamic response of glaciers to variations in both temperature and precipitation makes them excellent indicators of regional and global climate change over longer time periods than most other climate measures (Paterson, 1981).

Monitoring Objectives

Weather and Climate

- Determine variability and trends in climate for all high elevation networks through monthly and annual summaries of selected weather parameters including temperature and precipitation (also include soil temperature and moisture, relative humidity, radiation, wind speed and direction, and snow depth).
    - Archive measurements made at higher-frequency sampling intervals.
    - Winter monitoring should also include measurements of snow depth and density once per year at peak accumulation (should vary site by site) to estimate snow water equivalent (SWE).

Snow

- Determine long-term variability and trends in snow depth and snow water equivalent (SWE) in representative alpine areas and snow depth at high elevation weather stations.
- Determine long-term variability and trends in maximum yearly area extent of snowpack.
- Recognize trends in melt-out date at alpine index sites (onset of growing season and nutrient pulse).
- Determine status, variability and trends in annual water balance in select index basins (snow and rainfall contributions compared to subsurface water reservoirs and evapotranspiration).

Glaciers

- Determine status, variability and trends in mass balance of index glaciers and snowfields seasonally and annually on representative sites to determine variability and long-term trends (intended to allow inference to all glaciers in park and likely in region).
- Determine long-term trends and variability in glacier and seasonal snow contributions to stream flow.
- Monitor extent of all glaciers in parks at appropriate time intervals (depends on park and glaciers in park) to determine long-term trends.

General Monitoring Approach

The first goal is to monitor climate to determine whether and how climate is changing. A second and equally important goal is to use the monitoring information to help interpret and understand changes in other Vital Signs. The general monitoring approach should rely on intensive monitoring at a few index sites ("index" glaciers, stream gauged watersheds, and weather stations) and more extensive monitoring (e.g., monitoring snow cover with satellite imagery and infrequent mapping of all glaciers in a park). Locating monitoring sites should be done by considering the specific monitoring needs for each park as well as logistic and park management constraints (e.g., accessibility and compliance). Some components may be done in-house (by network staff or park-based maintenance, backcountry, or fire management staff) but most will likely be done cooperatively with partners with existing networks, equipment, and trained crews (i.e. USGS, NOAA and NWS, Western Regional Climate Center, Natural Resources Conservation Service, local water districts and managers, fire managers, avalanche forecasters, departments of transportation, ski areas, media, etc.). Because monitoring methods are substantially different, we separated Weather and Climate, Snow, and Glacier monitoring for protocol development purposes.

Weather and climate

Weather and climate monitoring should be done at a small number of automated, high elevation weather stations. (If power is not available, they should be powered by solar panel and batteries.) Locating sites should be informed by a cooperative evaluation of existing sites and monitoring needs underway between NOAA-WRCC (Kelly Redmond) and NPS (John Gross), as well as local considerations, such as power availability, accessibility for servicing and calibration, and park management needs and constraints (e.g., compliance with the Wilderness Act).

Measurements should be done at 5-minute intervals with hourly averages except for wind which should recorded as daily (hourly?) minimum and maximum wind speeds and hourly averages. All raw data should be shared with the National Weather Service for archiving. Real-time access to data (e.g. for avalanche safety, fire weather), would be a useful service for management and partners, if the equipment is affordable (including maintenance).

Monitoring temperature extensively across the park landscape to detect local variation in weather would facilitate spatial extrapolation of long-term trends away from stations; use cheap temperature sensors densely distributed across the landscape between and/or around automated weather stations. Further, if co-designed with deposition, water quality, and vegetation-soils monitoring, this data would help identify connections between climate drivers and ecosystem function. (Also see research and development section below.)

Costs include approximately $5,000 for a "typical" weather station and $2,000 per year to maintain it (assuming maintenance work by in-house GS-7 or -9 technicians). This includes annual recalibration. Solar/battery-powered stations cost more initially and annually. Telemetery enabled weather stations cost approximately $_X_ per station including data transmission costs. If networks work through an interagency agreement for maintenance with NWS or NRCS, maintenance costs would likely be higher.

Snow

Field monitoring of snowpack should be done on and near index glaciers (see glacier monitoring objectives below), in index stream-gauged basins (e.g. Loch Vale in Rocky Mountain NP), and in association with weather stations. Monitoring sites should be determined locally by considering patterns and affects of elevation, aspect, vegetation, site accessibility and the distribution of sites from other monitoring networks. Where necessary, stream weather stations and/or stream stage recorders should be installed.

Weather station and temperature sensor arrays should contribute to estimating melt-out date. Self-recording temperature sensors should be distributed across the landscape at ground level to monitor when different areas are snow-covered (i.e. temperature insulated at 0°C) and when areas become snow-free (temperature varies diurnally). At weather stations, snow depth can be measured hourly (when snow is present) using an acoustic snow depth sensor. Field measurements of snow depth and density (using a federal snow sampler [or Phil Taylor's lightweight version]) should be done at maximum snow accumulation to provide estimates of SWE (bracket samples to ensure reliable measurement). A water balance can be obtained by comparing stream measurements with snow measurements and meteorological parameters. Rating curves should be developed to measure the quantity and timing of runoff exiting the basin.

In addition to field efforts, NPS (networks) should obtain and archive Moderate Resolution Imaging Spectroradiometer (MODIS) data at time of maximum snow accumulation annually to document the yearly maximum extent of snowpack over time. Since many alpine areas are steep and rugged and since snowpack extends into subalpine and montane areas with extensive vegetation cover making interpretation of extent of snowpack difficult, research is required to understand how MODIS data relate to the actual extent of snow covered area annually.

Glaciers

Monitoring should be done at index glaciers located park by park considering representativeness, access, availability of historical data, other monitoring, park management policies, etc. Parks and networks should also consider glacier monitoring being done in the area, the region, and across the western U.S. in selecting index glaciers (e.g. U.S.G.S). Glacier mass balance should be measured for index glaciers and snow cover should be monitored across parks and networks (described above). Stream flow during summer downstream of index glaciers and index river basins should also be monitored. The "summer period" should be defined for each glacier based on the duration of the accumulation season.

Direct measurements are the most accurate way of determining glacier mass balance; point measurements of addition and loss of snow and ice are extrapolated across the glacier area to calculate mass balance. 2 to 5 stakes should be placed in holes drilled into the glacier surface in late spring. The height of the glacier surface should be measured twice yearly, at the accumulation and ablation peaks (late spring and late summer). Holes should be hand-drilled; stakes should be made of 1.5 m sections of 2.5 cm diameter PVC pipe connected by cable ties. When ice or snow melt exposes a joint between sections of pipe, the section of the pipe above the joint falls onto the snow surface. The stakes should be removed each fall. Transects of snow depth and density should be made to supplement the height measurements.

Glacier contributions to summer streamflow should be estimated using summer balance data from index glaciers and the area-altitude distributions of all glaciers in each watershed. Snow contributions to stream flow should be estimated using the streamflow, glacier streamflow contribution estimates, and weather station precipitation (and other) data. A research and development component is to establish a glacier runoff-altitude relationship specific to index sites (where this has not been done).

Finally, glacier perimeters should be mapped using high resolution GPS receivers in late summer, when the extent of glacial ice is most evident. Extent measurements should be conducted annually on index glaciers and at multi-year intervals on other glaciers (period should depend on park, network, glacier size, etc.). Extent measurements should be complemented by repeat photography (during GPS mapping) from benchmark locations for all glaciers.

Research and Development Needs

1. **Survey/inventory and evaluation of existing weather and climate monitoring sites** (relates to Objective 1 especially but also applies to snow and glacier monitoring). Likely a multi-network project to inventory existing monitoring stations/sites and evaluate them: are they the best sites, representative, accessible? Project might involve deploying many cheap instruments for several years in a park or network as a way to select best sites. This should include a way to develop a web site identifying the geographic locations and data available for each site. The Western Regional Climate Center has begun work on this project.

2. **Document lapse rates** (re: Objective 1). Document lapse rates (atmospheric cooling with elevation) for specific parks according to

topography, seasons, orographic effects, etc. Once calibrated, parks and networks can use weather station data to model weather information across parks. Some parks (e.g., Glacier NP) are done. For Glacier, USGS put in 7 stations for 3-5 years in the park. Cost was mostly labor (access by skis) to maintain and check stations. This could be done as a multi-network project – it would cheaper (maybe don't need long validation periods if you have a bigger project) and more rigorous. It might be a good cooperative project between NPS and NOAA for the mountain west.

3. **Paleoclimate** (re: Objective 1). Obtain paleoclimate information (data and interpretation of dendrochronology, lake cores, and other sources) of the climate trends and variability over the last 1,000 years. Include information on fire frequency and tree growth rates (indicators of drought and pluvial periods). There is a current USGS National Biological Information Infrastructure (NBII) proposal with Steve Gray to do some of this. NPS be able to work with USGS and NOAA (Kelly Redmond) to leverage a project for all parks and networks in the mountain west.

4. **Spatial variability and trends in soil moisture** (re: Objective 1). Similar to the project to document lapse rates. Project would likely deploy many cheap soil moisture and temperature sensors across parks to help understand and model soil moisture data using a few long-term monitoring stations.

5. **Identify index glaciers and stream flow sites** (re: Objectives 2 and 6). Identify the places in the parks with an established rating curve (could be sites with a calibrated USGS stream gauge or someplace with an established rating curve (e.g. Loch Vale in Rocky Mountain NP or sites in Yosemite NP). These are the places where a stage gauge could provide adequate monitoring information. To facilitate extrapolation to other (non-index) glaciers, establish a glacier runoff-altitude relationship relative to specific to index sites (where this has not been done).

6. Examine **spatial distribution of snow** depth using Lidar imagery obtained in winter during maximum snow accumulation as compared to summer with minimal snow cover (re: Objectives 2 and 6).
7. Correlate **glacier extent monitoring** with MODIS and other imagery acquired to monitor snowpack and other Vital Signs. (Re: Objective 8).

Potential Collaborators

The following list is the result of brainstorming by a small group of participants; it is not even close to an inclusive/exhaustive list. If you have additions or edits, you can send your comments to: Daniel_Manier@partner.nps.gov .

- Weather and Climate
    a. NPS-wide – Kelly Redmond (NOAA, Western Regional Climate Center); John Gross (NPS, WASO Inventory and Monitoring)
    b. Dan Fagre (USGS, West Glacier Field Station), Greg Pederson (USGS, West Glacier Field Station and MSU), Jill Baron (USGS, Fort Collins Science Center)
- Snow
    a. USGS – George Ingersoll, et al. (USGS Water Resources Division, Denver)
- Glaciers
    a. Dan Fagre (USGS, West Glacier Field Station)
    b. NCCN (Jon Riedel, North Cascades NP)

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Biogeochemical Cycling

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Justification

Atmospheric deposition and climate, especially precipitation and temperature, are primary drivers of alpine biogeochemical cycles. The alpine ecosystem responds quickly to climate-induced change owing to the harsh environment with much of the biota at the edge of their range. Further, atmospheric circulation patterns result in greater precipitation amounts and solute deposition in high mountain regions where nutrients are limited. Change in alpine soil microbial processes, aquatic chemistry, and nutrient budgets are reflected in the composition and health of the native (terrestrial and aquatic) flora and fauna. The high sensitivity to ecosystem drivers (deposition, climate) can result in viewing the alpine ecosystem as the "canary in the coal mine". (For a more thorough discussion of alpine environments and biogeochemical cycling see: Billings 1973, Billings 1988, Bowman and Seastedt 2001, Bowman et al. 2002).

To detect incipient change and its magnitude in terrestrial ecosystems, it is best to initially emphasize process studies. Successful scaling up of results from replicated points within a discrete ecosystem to the landscape level is dependent on understanding the processes that underlie observed larger-scale spatial and temporal patterns. Linkages between terrestrial and aquatic ecosystem components dictate that there is overlap of key measurements, such as wet and dry deposition and snowpack distribution. The I&M design for each ecosystem must be fully complementary. However, here we focus primarily on the terrestrial component and the integration of precipitation amount and timing, atmospheric deposition, the extent and duration of snowpack and its chemistry, and stream water solute export from discrete alpine watershed ecosystems. Integration should occur using spatial co-location and/or overlapping sampling within a sentinel watershed. The sentinel watershed can be used to define and refine variation estimates for target populations and processes, and should serve to integrate results from intensive study of priority Vital Signs (e.g. climate, deposition, vegetation composition, water chemistry). The monitoring objectives for the sentinel watershed are long-term, and a primary criterion for site selection must consider minimizing short-term impacts as from visitor use and disturbance associated with monitoring.

Monitoring Objectives

Landscape patterns (aerial photography, or MODIS, surveys with field validation)

- Determine variability and trends in annual snowpack extent, duration, and snowpack water equivalent (SWE)? And, what is the trend in annual and seasonal rates and timing of snow, ice, and glacier phenology (e.g. melt-off, break-up, accumulation, and freeze-over)?
- Determine patterns and trends in tree-line and timberline boundaries. (The hydrologic and chemical patterns and exchange rates across this gradient need research and potentially monitoring.)
- Determine the status and trend in number, distribution, and P/A ponds, tarns, etc. (i.e. water bodies with >2m depth of standing water.)

Field Biogeochemistry

- Determine status, variability and trend in the "standard suite" of cations and anions (N, P, K, S, Ca, Mg, Zn, Mn) in atmospheric deposition (loading) based on combined SWE and chemistry and precipitation chemistry.

- Determine status, variability and trend in soil solutes (especially nitrogen mineralization rates and/or NH_4 vs. NO_3) using simple, *in situ* techniques (e.g. resin bags/capsules/spikes) and collection and analysis of soil samples (e.g. carbon-nitrogen ratio). Trends should be established for biannual periods, summer and winter (sampling in spring immediately after melt-off and autumn as soil temperatures approach freezing and/or the first persistent snow occurs.)
- Determine the patterns, variability and trends in fine scale (within alpine watershed) interactions between weather/climate and nutrient cycling.
    - This approach requires an intensive grid with continuous or high-frequency measures to capture local spatial/temporal variability within and among atmospheric and soil temperatures, moisture contents, and chemical composition. Based on these baseline studies, permanent monitoring sites are located as a subset of the original grid to represent mean or median conditions, or to observe particularly sensitive sites. Ultimately, establishment of permanent sentinel watershed monitoring site(s) within each park (this group noted that, 10 long term sites that compliment existing sites (e.g. LTER) would be a great contribution).

- Determine the status, variability and trend in dry deposition (chemical). Determine the effect, if any, of these chemicals on native vegetation and wildlife, and water quality.
    - Suggested within this group that, this is <u>not worth the effort</u>; problems are analytical including high variability and low power (alternative suggestions: use snow, sediments, fish tissues, etc. as integrators). However, due to the perceived importance of this issue for the Sierra Nevada Network, it is included here; it is not currently a likely candidate for “universal” implementation.

Systemic / community response

- Determine status, variability and trend in plant communities and correlate these (through overlapping sampling distributions) with patterns in climate and atmospheric deposition. (As a response, plant community structure and composition are a surrogate for other processes, e.g. in the soil, that are not practical to monitor.)

- Determine the status, variability and trends in hydrology, sediment loads, and chemistry of stream and lake waters (water chemistry, temps) and effects on aquatic biota, wetlands, etc. (not necessarily in alpine, but alpine origin for downstream effects).
    - Temporal resolution should be able to recognize seasonal flow pulses, late summer inputs, and differences in solutes and sediments (especially nitrogen and phosphorus seasonally. Major changes in hydrology occur in the meanders within floodplains below the alpine region – these may include toxic organic releases. (Other notes: Integration of processes across system is important. Hydrology is a weak point. Flowpaths can be tracked.)

General Monitoring Approach

Monitoring must begin with collection of baseline information about spatial and temporal patterns of key factors that drive biogeochemical processes in the alpine zone. Temperature and precipitation, particularly the timing and extent of snow cover, have been identified as key process drivers in this zone. Successful change detection depends on understanding existing patterns and variability, so that the spatial distribution and frequency of samples in long-term monitoring sites is designed to efficiently and accurately estimate trends.

Monitoring biogeochemical cycles should address the complex coupling among climate, hydrologic, geologic and biologic processes on the landscape. A monitoring protocol design which co-locates studies in the same watersheds should best capitalize on the integrated nature of both climate drivers and process responses. Design and field efforts should begin with extensive survey designs (wide distribution for a select group of interdisciplinary variables) to assess the spatial heterogeneity of each target population/driver/process. Based on sensitivity and dynamics of each variable, a smaller set of permanent, long-term monitoring sample sites should be defined which represent the mean and variance of the target population. While we think this is the best approach, we also anticipate challenges in finding watersheds which should simultaneously meet each sub-discipline's sampling criteria. The watersheds which do meet sampling criteria should be "sentinel sites." Coordinated, intensive sampling occurs in these sentinel sites. The sampling design should include weighted distribution based on natural gradients in abiotic features such as elevation and aspect; this promotes correlation analyses and spatial extrapolation of results through modeling. Initial surveys of both the drivers and responses should occur across a range of locations and the results from early monitoring determine the nature and location of long term, intensive monitoring. The GRTS methodology developed by EPA is recommended for creating the spatially weighted sample design.

Field sampling should be structured and interpreted through integration with remotely sensed information and monitoring. Satellite based products such as Landsat and MODIS have been suggested, however, significant processing problems must be resolved before these methods can be considered reliable (see Woodward et al. 2003). For example, MODIS raw data masks out 'clouds' that are really probably snow, and thus this cloud-masking effect must be better understood before this method of snow mapping can be used operationally. For the purposes of many types of alpine monitoring, digitized aerial photographs may still be the best tool to use.   Aerial photographs can be used to determine trends in several key abiotic and biotic features, such as change in snow covered area and snow melt patterns, the response of treeline and tree islands, and changes in the distribution and character of aquatic and wetland features.

Field sampling should combine single point measurements, such as meteorological climate stations or stream gauges, with distributed sampling, such as long term monitoring plots for vegetation change and soil condition and function. Snow depth sampling in the field complement aerial photographs of snow area and melt patterns. Co-location of sampling schemes should be a priority. For example, we suggest monitoring snow-water equivalent (SWE) and wet deposition in the watershed(s) adjacent to meteorological station(s), with soil sampling for carbon-nitrogen ratio or soil respiration and long term vegetation plots distributed across the adjacent landscape. Surface water solutes, such as dissolved inorganic nitrogen (DIN), dissolved organic carbon (DOC), and perhaps dissolved organic nitrogen (DON), can be good indicators of change in stressed ecosystems. Field sampling for these solutes can easily include a suite of additional inorganic elements at nominal additional cost. Several of the inorganic solutes can complement results found for DIN, DOC, and DON. DOC production, a result of soil organic matter decomposition, is a sensitive indicator of climate change and an important energy source for the base of the aquatic foodweb. The production of DIN, largely from mineralization of soil organic nitrogen and in some areas atmospheric DIN deposition, is also quite responsive to climate change especially in soil moisture and temperature, and is the most common limiting nutrient for terrestrial vegetation, soil microbes, and seasonally in the aquatic ecosystem. Dissolved organic phosphorus (DOP) and inorganic soluble reactive phosphorus (SRP) are important limiting nutrients in the terrestrial and aquatic ecosystem along with potassium (K) in the terrestrial ecosystem. Solutes such as calcium (Ca) and silica (Si) are good indicators of the flow path snowmelt takes to streams and lakes.

In addition to the sentinel sites, with intensive overlapping and co-located sampling, alpine systems need to be *extensively* monitored across park units. These protocols should necessarily be less intensive than in the sentinel sites, but use a set of common measures to capture spatial and temporal variability across these landscapes. Due to the wide distribution and occasional (3-5 year for sampling, annual for data loggers) revisit plan of these sites, we must use practical (e.g. low/no power needs, durable equipment, light to carry and distribute, minimal equipment left in field) and repeatable (e.g. sustainable financially, clearly understood and describable techniques) measurements. The distribution of these sites across the alpine landscapes of parks should be determined by extrapolating and estimating landscape level patterns of variability in the target population or process based on initial intensive/extensive sampling of target populations within parks using landscape models. The candidate measures include snow chemistry, water chemistry, soil chemistry (resin bags or small sample removal), vegetation composition and structure. (A few variables done well will be much more valuable than many done inconsistently because of funding.)

Additional efficiencies may come from novel cross-network collaboration with respect to both equipment and personnel. Implementing research in phases might allow us to maximize on investments in equipment which can be deployed in waves. For example, small soil temperature probes, used to determine baseline patterns of variability for the first several years in any given network, can be redeployed in another network. Specialized sampling, for example soil respiration, would be analytically and economically optimized by having a single specialized crew responsible for the measurements at each park (among multiple participating networks).

Research, Development and Inventory Needs

To better carry out the alpine ecosystem Monitoring Objectives and evaluate likely complimentary monitoring variables, a series of research and development needs should be considered. A number of topics discussed at the session on biogeochemical processes are listed here without priority.

Dissolved organic carbon (DOC) and nitrogen (DON) in soil, stream, and lake water potentially play major roles in the transport of energy and nutrients from the terrestrial to aquatic ecosystems. The ecological role and methods of analysis for DOC, especially its sensitivity to climate change, are better defined than for DON. The ratio of dissolved inorganic nitrogen (DIN), especially nitrate, relative to DON may also be an indicator of the relative importance of atmospheric DIN inputs to the aquatic nitrogen cycle. However, research results to date are unclear as to the relative importance of DON in the nitrogen cycle, and the method of analysis for DON is not as precise as for DIN. DOC could be included as a monitoring variable in soil and surface water at this time. More evaluation of the analytical limitations for DON should precede its general use as a monitoring variable unless the additional cost of its analysis is marginal.

The general absence of overstory vegetation in the alpine makes soil processes especially sensitive to climate change. Alpine climate and soils are spatially and temporally diverse. There can be significant spatial and temporal variation in alpine hydrologic and soil processes owing to elevation and aspect interacting with solar radiation. Several direct and indirect indices of soil processes (carbon and nitrogen mineralization rates, temperature, moisture) can be rather easily monitored intensively and extensively. It is recommended that the NPS I&M program organize a team approach to intensively instrument and monitor for one year each "sentinel" alpine study sites to quantify seasonal change in spatial variation of solar radiation, air temperature (10, 40, 70 cm above soil surface for snowpack dynamics), soil temperature, soil moisture, soil respiration rates, and nitrogen mineralization (resin bags). This dataset should be analyzed to find the optimal distribution of a subset of points where long-term monitoring of selected soil processes should be implemented.

The input of airborne polychlorinated organic pollutants may be significant for higher elevation alpine ecosystems. However, the published literature is unclear as to whether such inputs increase with elevation or in an ecosystem without a vegetation overstory. It is also poorly documented as to the effect of organic pollutants in the alpine ecosystem. The sampling and analysis of organic pollutants is expensive and labor intensive, and the objective interpretation of results requires substantial skill. At present it is recommended that such sampling not be conducted until its value to the objectives of the I&M program is much better defined. If there is a local issue regarding deposition of organics, it should be addressed with support from other programs within or outside the NPS.

Dry deposition of airborne nitrogen and sulfur compounds could be significant in some alpine ecosystems. Limited research to date indicates dry deposition can make up 30 – 50% of total nitrogen and sulfur inputs near intensively developed regions. However, the ecological importance of such inputs to the alpine ecosystem is unclear. Also, the monitoring equipment requires access to line power, and the results from the existing protocols are complex to interpret. Maintaining the monitoring equipment is labor intensive and generally requires weekly or more frequent field checks by skilled technicians. At present it is not recommended the NPS I&M program for alpine ecosystems include this element until the ecological importance is better understood and simpler and less labor-intensive monitoring protocols are developed.

The below-ground microbial community can make up >99% of ecosystem biodiversity, regulate nearly all nutrients available to the above-ground biota, produce 50% of ecosystem production, and generally is nitrogen limited. The combination of warming temperatures and atmospheric nitrogen inputs has potential to significantly modify the alpine nitrogen cycle. Research results to date suggest the diverse soil microbial community should initially be the most responsive to such modification since it has the capacity to retain large amounts of nitrogen. Its response should likely be a change in biomass and diversity of functional groups that perform essential soil processes. There are a number of promising indices under evaluation (enzymes, microtitre plates, soil carbon and nitrogen mineralization rates, etc.) that could serve as practical monitoring tools of soil microbial and fine root activity. At present we suggest the NPS I&M program consider active support of research on these processes and indices in cooperation with other externally funded research in alpine ecosystems.

The flow path of alpine snowmelt and precipitation from the terrestrial to aquatic ecosystem is a major factor regulating the amount and quality of atmospheric and terrestrial solutes reaching the aquatic ecosystem. Discrete alpine watershed ecosystems are often dominated by porous soils that permit percolation of nearly all snowmelt. Conversely, where the alpine contains fine-textured soils and/or a shallow soil active layer (zone of annual freeze-thaw) a significant fraction of snowmelt may move by surface lateral flow little altered chemically by alpine soil. There are a number of good chemical indicators (calcium, silica, magnesium, nitrate, carbonate-bicarbonate, and sulfate) of temporal and spatial change in this hydrologic flow path to the alpine stream or lake that are incorporated in the proposed monitoring of surface water solutes. It is recommended there be an early systematic evaluation of these solutes in alpine surface waters as indices of alpine flow paths and soil influence on surface water quality in and leaving the alpine ecosystem.

A concern in some regions is the ecological ramifications of atmospheric nitrogen loading for alpine vegetation composition, diversity, and biomass. There is a relatively good research record evaluating alpine vegetation responses to additions of nitrogen and, to lesser extent, phosphorus. Some records are long-term. However, most of this research has been confined to selected geographical regions (New England, Central Rocky Mountains, Sierra Nevada, and Alaska's North Slope) that do not include the spectrum of alpine vegetation communities and stressors. If NPS alpine ecosystems are found which can truly add to the scientific knowledge of vegetation response to present or anticipated atmospheric inputs, the NPS I&M program should actively support small scale but highly replicated experimental study of nutrient and natural abundance isotope studies in such systems.

Potential Collaborators

Due to the ad hoc and dynamic nature of staffs, this list must evolve and be maintained over time. We recommend establishing a PI for analysis and synthesis; this person should be informed on site characteristics and data collection, methods, etc; this person should assess the data annually (even if only 3-5 year reports) – this may be internal to the network, a science panel rep. or other collaborator. Networks should allocate funds (retainer) for this person to analyze data annually and report back. This must be network specific. Additionally, certain sampling techniques are conducive to establishment of traveling crews who are trained to use particular equipment/processes. This would reduce variability among methods, and disperse the overhead costs of maintaining equipment, training crews, etc. This approach would require collaboration among parks and networks to employ a single laboratory and PI. Applications may include soil nutrients using resin bags, soil respiration, snow chemistry, stream chemistry.

University faculty and staff are particularly suited for the task of coordinating and performing field sampling. This must be network specific, and should likely be adapted over time to bring in new collaborators because people change/move, etc. The following list is the result of brainstorming by a small group of participants; it is not even close to an inclusive/exhaustive list. If you have additions or edits, you can send your comments to: Daniel_Manier@partner.nps.gov .

ROMN:
- CU / CSU – e.g. Bowman, Seastedt, Cooper, Hobbs
- USGS – Baron, Clow, Campbell, Mast Ingersoll, Fagre, Stottlemyer
- Malanson et al. (U. of Iowa? - geography, numerous papers on GLAC)
- U. Montana – Running, et al.

GRYN:
- MSU- Graumlich, Whitlock
- USU – Van Miegroet; Remote Sensing: M. White, Ramsey, Edwards (USGS)
- CSU – Romme?

NCCN – KLMN:
- U. Washington – Edmonds et al.
- OSU /Andrews Exper. For. – Harmon et al.
- USGS/OSU - Larsen
- USGS FRESC (Corvallis) – Parakis
- EPA – McCain, Compton

SIEN:
- WMRS – Holmquist
- UC Merced (Sierra Nevada Institute) - Bayles
- USGS – Clow, Carpenter

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Aquatic Systems - Alpine Lakes

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Justification

Lakes and ponds (lentic) systems are an important component of nearly every alpine landscape. The ecology of alpine lakes is intimately linked with the local watersheds they occupy. In addition, lentic systems support a broad spectrum of ecological services including critical habitat for facultative and obligate aquatic taxonomic groups, support for many terrestrial taxonomic groups, nutrient and hydrologic cycling. Alpine lakes are also very sensitive to perturbation, both at local and landscape scales. Accordingly, they were selected as ideal aquatic systems for long term monitoring in the alpine zones of the western NPS parks.

Here, we focus on an integrated approach to monitoring these systems based on quantifying habitat (e.g., physical structure, flow regime), water chemistry and physical attributes as well as biological measures to generate comprehensive assessment of alpine lake systems. A defining biotic feature of most high elevation lakes is their lack of fish (unless they have been stocked); this is due to the dispersal barriers imposed by waterfalls, steep runs, and flow patterns. Fishless systems have planktonic food-webs dominated by low densities of predacious copepods, large herbivores and several species of rotifers, flagellates, diatoms and cyanobacteria (McKnight et al. 1991, Stockner 1991, Thomas et al. 1991). Because high-elevation lakes and streams are very sensitive to low levels of nitrogen deposition, quantifying seston and benthic assemblages is likely an important vital sign.

Monitoring Objectives

This is an extensive list of monitoring objectives, and as such would not likely be implemented in its entirety in any one network. But from this list, networks can select a subset of measures based on regional and larger continental scale issues, especially those being monitored in other networks. This list is not complete and does not imply any priority in objectives. Note that all example monitoring objectives below include static (status) and trend analyses. The accumulation of status measures over time, in a systematic, well-designed spatial-temporal distribution results in data for trend analyses – both of these are valuable for management decisions. Ideally, each trend related objective should be coupled with a statement of magnitude and power such as, "Trend in a given measure or metric is defined as an 5% change / 20 year period, with a Type I error of 0.10 at 80% power" – however, these values have not been stated for all objectives. In all cases, <u>sampling should occur during a clearly defined, late-summer period</u> to help control for variance due to inter-seasonal variability.

Survey Sites

Physiochemical

- Determine status and trend of lakes (absolute and proportion of population) above derived critical loads in water quality parameters (defined for each park/network/region) during a defined late summer index period.
    - Mean concentration of nitrate.
    - Total nutrient loading (established via resin chambers).
- Determine status and trend in physical parameters such as water temperature or basic weather attributes status and trend summer temporal (e.g., diel) patterns.
    - Summer-long (or summer month 1-2-3) mean water temperature
    - Basic weather attributes at the population scale.

Biological

- Determine status and trend in lakes (absolute and proportion of population) during a defined late summer index period with a Phytoplankton Index of Biotic Integrity above established or derived narrative/quantitative criteria.
  - Zoo- and phytoplankton Shannon diversity above the 90^{th} (arbitrary) percentile.
- Presence of any amphibian taxonomic groups (the simplest measure, many other more intensive measures exist, e.g. community composition or diversity).
- Presence of any fish taxonomic groups (again, the simplest measure).

Habitat

- Determine status and trend in shoreline complexity (e.g. proportion with an index above the 90^{th} (arbitrary) percentile).
- Determine status and trend in lakes with more than 50% of their shoreline with > 90% perennial vegetative cover (% are arbitrary).

Intensive/Sentinel Sites

Phenological

- Determine status and trend in phenological events (e.g., ice out/melt out, green up, insect emergence, flowering dates, and turn-over dynamics).

Physiochemical

- Determine status and trend in seasonal nutrient loading in sentinel lakes' catchments.
  - Determine status and trend in deposition in alpine zone
  - Determine status and trend in movement of nutrients from upland to aquatic systems
- Determine status and trend in seasonal water temperature and conductance in sentinel lakes.

- Determine status and trend in the mean seasonal concentration in water quality parameters (express relative to the site specific critical loading for that parameter).
- Determine status and trend at the lake outlet hydrology as indicators of snowmelt input to sentinel lakes (ideally with bedrock).
- Determine status and trend at the lake outlet and/or deepest point water chemistry at each sentinel lake seasonally. Depth integrate if stratified, otherwise at standard depth.

Biological

- Determine status and trend in the seasonal zoo- and phytoplankton based Index of Biotic Integrity for sentinel lakes and express relative to any criteria.
- Determine status and trend in the presence of amphibians (the simplest measure, many other more intensive options exist).
- Determine status and trend in presence of fish (again, the simplest measure).

General Monitoring Approach

Discrete alpine resources (lakes and non-riparian wetlands) should be assessed using a hybrid sample design that includes sentinel sites with more intensive instrumentation and sampling frequency and survey sites distributed across lakes in the alpine zone for population inference. Survey sites should be selected using a spatially balanced design (GRTS; Stevens and Olsen 2004) and should have a complex panel structure and revisit schedule to capture inter-annual variability. Alpine streams are assessed as part of a larger sample design spanning the entire elevational gradient in a park (using the same hybrid approach). However, results from lotic systems can be integrated with lakes (especially sentinel sites) in at least qualitative ways.

Sentinel sites may be selected using 1) a subset of survey sites, or 2) a GradSect design or some other applicable model (e.g., "sensitivity mapping" for ANC), but in reality will likely be 3) an adoption of existing monitoring (e.g., LTER), high visibility locations, or access points that allow multi-season data collection (or some combination of these approaches).

In summary, our selection of indicators or Vital Signs focus on measures of biological assemblages to generate metrics (IBIs) correlated with the ecological integrity of lakes. To develop and understand these metrics we must also measure chemical and physical aspects of lakes (which, of course, may also have real value in and of themselves). Our primary focus for non-biological indicators include the ground and surface water hydrologic drivers of lentic systems, physical habitat such as substrate and shoreline morphology, water physiochemical attributes (especially those connected to trophic status and nutrient inputs) and landscape-scale composition and dynamics of the catchments above each sampled lake.

Both sample designs (but especially the first) require maps of alpine lake distribution. Our working model uses the National Hydrograph Database (NHD) as modified by individual parks. Both design strategies include meso- and landscape-scale measures of lake composition, structure and hydrologic parameters. Finally, the two designs should be as linked as possible through use of a subset of common indicators, response designs, sample design details, and in integrated analyses of spatial and temporal patterns.

Draft Table of possible measures in alpine lakes

Measures and general protocols: Sentinel Sites
Protocol: Frequency based on hydrograph, but at least 4 times/year, base, rising, peak, falling; Site protocols function of lake size, catchment area, and/or degree of mixing; Depth integration and interval or profile function of mixing status Note that all applicable atmospheric deposition, snow and climate data would ideally be in the sentinel sites catchment; Water chemistry probably at outlet, grab samples, local site is well mixed; SOP exists
<u>Physiochemistry</u>
Temp, DO, turbidity, TSS, etc.
pH, alkalinity, etc. not filtered or preserved
cations/anions filtered
chlorophyll a, etc.
nutrients: DOC, TN, TP, DON, DOP, protocols exist (LTER), DON is tricky, filtered (ashed), not clean methods
Additional as needed: toxics, metals (Hg), pharmaceuticals, pesticides, POP, and stable water and/or nutrients isotopes
<u>Physical Habitat</u>
Depth, shoreline structure (complexity), littoral vegetation cover (note that is this appears to be a growing issue, may need to switch to a more robust approach), fish cover, etc.; note that frequency of these over time will be different and may not be done at every sampling period
Discharge (weirs, so issues with implementation), pressure transducer with logger

Catchment characteristics from landscape VS: cover, spatial configuration, geology, soils, topography, etc.
<u>Phenological</u>
Ice out/melt out, green up, insect emergence, flowering dates, and lake turnover dynamics.
<u>Biological</u>
Tows and substrate for zoo/phyto (exact protocols will vary with season)
Key species/assemblage presence absence: Herps, invasive taxonomic groups, fish

Measures and general protocols: Survey Sites (note red text indicates those measures not likely for survey sites)
Protocol: Location based on spatially balance probability survey; Frequency based on late summer index period and hydrograph, once per year or as determined by panel designs (Sept/Oct ideal for WQ; July-Aug for Biota)… reality is it will span this interval and have trade-offs for all measures; Site protocols function of lake size: catchment area, and/or degree of mixing; Depth integration and interval or profile function of mixing status; Water chemistry probably at outlet, grab samples, local site is well mixed; SOP exists
<u>Physiochemistry</u>
Water chemistry probably at outlet, grab samples, local site is well mixed; SOP exists
Temp, DO, turbidity, TSS, etc.

pH, alkalinity, etc. not filtered or preserved
cations/anions filtered
chlorophyll a, etc.
nutrients: DOC, TN, TP, DON, DOP, protocols exist (LTER), DON is tricky, filtered (ashed), not clean methods
Additional on as needed: toxics, metals (Hg), pharmaceuticals, pesticides, POP, and stable water and/or nutrients isotopes
Note that all applicable atmospheric deposition, snow and climate data would ideally be in the sentinel sites catchment
Phenological
Ice out/melt out, green up, insect emergence, flowering dates, and lake turnover dynamics.
Physical Habitat
Depth, shoreline structure (complexity), littoral vegetation cover (note that if this appears to be a growing issue, may need to switch to a more robust approach), fish cover, etc.
Discharge (weirs, so issues with implementation), pressure transducer with logger… change to flow meter if done at all?
Catchment characteristics from landscape VS: cover, spatial configuration, geology, soils, topography, etc.
Biological
Tows and substrate for zoo/phyto
Key species/assemblage presence absence: Herps, invasive taxonomic groups, fish

Research, Development and Inventory Needs

Several critical R&D needs are required for effective monitoring in alpine systems. Foremost is the development of criteria or thresholds of ecologic effect in the stressors that impact alpine lakes. These include both biological (such as seston IBIs) and physiochemical such as nutrient loading and trophic status.

Other research needs are listed below:

1. Identifying or confirming that seston is the best assemblages to focus on. A key piece of this will be researching the *availability and applicability of existing IBI* models alpine lakes in the setting of each park. IBIs hold much promise, but we must be sure that for lakes with unpredictable yet recurring influences of climate-induced variability (e.g., long-term high water periods, droughts, fires, etc.) scoring ranges are calibrated for the specific hydrologic history pre-dating any sampling year (Wilcox et al 2002).
2. Developing or adopting an existing *classification approach for alpine lakes* and identifying key types that are most useful and efficient for long term monitoring. Multiple approaches to this issue exist and we do not anticipate many issues with adapting these to our objectives.
3. Collate and evaluate existing sample frame coverages (NHD). This is also not likely a difficult step.
4. Developing a research plan for *novel IBI creation* where needed. This includes defining reference conditions for each park. IBIs can be created using the initial stages of actual data collection at monitoring sites by including (usually hand picked) gradient sites. Given the relatively pristine state of many alpine lakes in NPS parks, some gradient sites may be outside of a park in more disturbed areas in order to include more diverse communities of resilient taxonomic groups. Even if a novel IBI is not

needed, initial data from monitoring stations should be calibrated and tested to refine existing models for specific application.

5. *Identifying sentinel site locations.* These may be collocated with existing long term monitoring locations or issue driven (i.e., where known problems, at risk or sensitive populations exist).
6. *Developing or adopting SOPs* for all biological, chemical, physical and landscape measures. Many SOPs will be modifications of existing approaches. An essential component of this step will be to generate cost estimates for specific objectives and their set of measures.

Appendix A: The following lists include key processes for alpine lake monitoring.

Physical:

1) Snowpack accumulation and melting and its effect on surficial/ground water hydrology, temperature, DO, turbidity, etc.
2) Summer climate including non-snow precipitation, radiation, wind and its effect on surficial/ground water hydrology, temperature, DO, turbidity, etc.
3) Rain on snow and its effect on surficial/ground water hydrology, temperature, DO, turbidity, etc.
4) Phenological: snow melt, ice out, lake turnover, drying of ephemeral features,
5) Extreme disturbances: rock/snow avalanches, debris flows
6) Solar Radiation
7) Wind
8) Ground water hydrology; hyporheic zones

Chemical:

1) Atmospheric deposition of nutrients (N, S), acidity, base cations, toxics (Hg, pesticides) into snow their concentration and loading during melting and their impacts on stream/lake water quality and biotic composition; temporal variation in chemical species in surface waters
2) Atmospheric deposition of nutrients (N, S), acidity, base cations, toxics (Hg, pesticides) into rain their concentration and loading during melting and their impacts on stream/lake water quality and biotic composition; temporal variation in chemical species in surface waters
3) Dry deposition (mostly during the summer) of nutrients (N, S), acidity, base cations, toxics (Hg, pesticides) their concentration and loading during melting and their impacts on stream/lake water quality and biotic composition; temporal variation in chemical species in surface waters;
   a. The interaction of dry deposition and summer rain events (e.g., wash off of dry deposition)
   b. Wet: dry ratios may be higher in western parks

Biological:

1) Succession
    a. Upstream from beaver meadows in the sub alpine
    b. Lake dynamics
2) Population dynamics
    a. Demographic patterns and their impacts on patch dynamics; pattern formation in streams and lakes
3) Food web dynamics
    a. Community structure in particular fish vs. fishless alpine lakes
    b. Predation/Herbivory
        i. Elk-willow
    c. Eutrophication
4) Invasive, non endemic species, pathogens
    a. NZ mud snail?
    b. Chytrid fungus (in herps)
    c. Whirling disease
5) Riparian structure and composition
    a. Light regimes
    b. Large/small woody debris, COM/FOM…. allochtonous input